# Characterization and Modeling of Inherent Optical Properties in the Gulf of Maine

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## LONG TERM GOALS

Our long term goal is to contribute to a fundamental understanding of the sources of biological, physical, and optical variability in coastal ocean systems. Particular focus is on applications useful for studying important ecological processes and the links between phytoplankton properties and physical processes in coastal regions.

## OBJECTIVES

The overall objective of this project is to improve understanding of the Gulf of Maine and Georges Bank system through characterization and modeling of optical properties in the context of physical and biological processes. We wish to describe the processes controlling space/time variability in the various constituents (CDOM, phytoplankton, sediment, detrital particles) that determine the optical properties of this region. Specific objectives fall into two categories:

Observational/Database Objectives

– Complete processing and quality control for optical and hydrographic data collected during 5 cruises to the GOM during 1997-1999,

– Compile a readily accessible database of spectral optical properties for the GOM from these cruises, as well as other recent research programs,

– Use the database to develop parameterizations of optical variability that will be used in the numerical simulations;

Modeling Objectives

– Implement a hierarchy of optical models (from CDOM as a single passive tracer to a full ecosystem model with optical linkages) into the three-dimensional circulation model; conduct

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**Our long term goal is to contribute to a fundamental understanding of the sources of biological, physical, and optical variability in coastal ocean systems. Particular focus is on applications useful for studying important ecological processes and the links between phytoplankton properties and physical processes in coastal regions.**

15. SUBJECT TERMS

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"process-oriented" simulations to examine how the relative contributions of the various optical constituents vary spatially and temporally,

– Construct data-driven hindcast simulations based on field data from 1997-1999; use the coupled models to distinguish spatial from temporal variability in the observations.

**APPROACH**

Optical properties have potential to provide information about biological and chemical constituents present in coastal ecosystems; however, signals can be difficult to interpret because of the complexity and multidimensional (time, space, wavelength) nature of the relevant processes. Three-dimensional modeling offers an attractive framework for synthesis and understanding of the factors contributing to optical variability. We are taking advantage of an extensive optical dataset collected in previous work by one of us and a realistic three-dimensional circulation model coupled to an ecosystem model by the other. Our new work will include development of methods to parameterize optical variability (based on observations) within a hierarchy of models from a single passive tracer to full coupling with the ecosystem model. "Process-oriented" simulations and hindcast simulations with data assimilation will be used to examine how the relative contributions of different optical constituents vary and to distinguish spatial from temporal variability.

The Sosik laboratory is responsible for the construction of the optical database and development of the parameterizations required for the optical model. Brittan Rabinovitch (Research Assistant) and J. Ru Morrion (Postdoctoral Investigator) are assisting the principal investigator with this work. Personnel in McGillicuddy's group are designing the numerical experiments, implementing the optical models in the context of the current coupled physical-ecosystem model framework, and constructing the simulations. Valery Kosnyrev and Olga Kosnyreva (both Research Associates) are assisting the principal investigator in these activities. Sosik and McGillicuddy work together on interpretation of the simulation results.

**WORK COMPLETED**

During the past year we have continued to work on analysis of our optical database. For the Gulf of Maine, our focus has been on statistical interpretation of spatial and temporal variability in absorption by CDOM. We have also developed a more robust method for determining quantitative absorption coefficients from ac-9 data; this iterative correction approach has been described in detail in Morrison and Sosik (2002) and is being prepared for peer-reviewed publication. In related work, we have worked toward final publication of results described sources of optical variability on the nearby New England shelf (DuRand et al. 2002, Green et al. 2003a, 2003b, Martin Traykovski and Sosik 2003, Green and Sosik submitted).

Subsequent to our investigation of the large-scale seasonal fluctuations of phytoplankton abundance in the Gulf of Maine (using an adjoint data assimilation approach described in our FY 02 report), we have turned our attention toward a more complete ecosystem model. The tasks we have worked on were to

(1) Develop a simple biological model that captures the main ecosystem dynamics that control phytoplankton abundance in the Gulf of Maine.

(2) Optimize the biological model parameter values by fitting the model in 1-D to biological data from Wilkinson Basin. Revise the biological model parameterizations if necessary. The model's ability to simulate the observed seasonal cycles will yield a basic understanding of the primary 1-D physical-biological interactions.

(3) Incorporate the optimized biological model into a previously-developed 3-D physical simulation of the Gulf of Maine. Conduct 3-D physical-biological simulations of the spatial and temporal distribution of phytoplankton in the Gulf of Maine.

(4) Diagnose from the simulations the key physical processes that control the biological processes and phytoplankton abundance, including the observed temporal and spatial anomalies in optical properties.

**RESULTS**

With use of our new iterative ac-9 processing scheme we have substantially improved recovery of accurate absorption coefficients particularly for waters with values < 1 $m^{-1}$, as in most of the Gulf of Maine. We compared our method to two other scattering correction approaches: 1) a simple spectrally neutral offset (715 nm) and 2) a more complex model of Zaneveld et al. (1994) that allows scattering errors to vary spectrally in proportion to estimated scattering (Figure 1). An additional advantage of our iterative approach is that it includes a spectral decomposition step that provides separate estimates of phytoplankton and detrital absorption.

Data-driven, physical-biological simulations were conducted for the western Gulf of Maine to shed light on the physical and biological processes that control phytoplankton abundance and variability. First, a 5-box (NO3-NH4-Phy-Zoo-Det) nitrogen-based ecosystem model was developed which describes the main top-down and bottom-up controls on phytoplankton biomass. The biological model parameter values were optimized for the Gulf of Maine by fitting the model to 1-D (z,t) biological time series data from Wilkinson Basin, using Powell's conjugate direction method (Evans, 1999). The collected $NO_3$ and $NH_4$ data set is available online at http://www.whoi.edu/science/AOPE/people/landerson/GOM/no3_data.030520. Phytoplankton data are from O'Reilly and Zetlin (1998), zooplankton biomass based on Meise and O'Reilly (1996), and detritus data from MWRA observations. The optimized biological model was then incorporated into a previously-developed 3-D physical simulation of the western Gulf of Maine for March-June 1993. Figure 2 shows snapshots of phytoplankton abundance from this simulation. According to the simulations, a wide variety of processes contribute to phytoplankton variability in the western Gulf of Maine, including mixed-layer depth (as influenced by winds, surface buoyancy flux, riverine outflow and bathymetry), wind-driven coastal upwelling and downwelling, horizontal advection by winds and riverine outflow, wind-driven horizontal diffusion, and grazing by zooplankton. The simulations are currently being diagnosed for the main processes that control phytoplankton abundance at each location and time, and the fluxes between model compartments quantified.

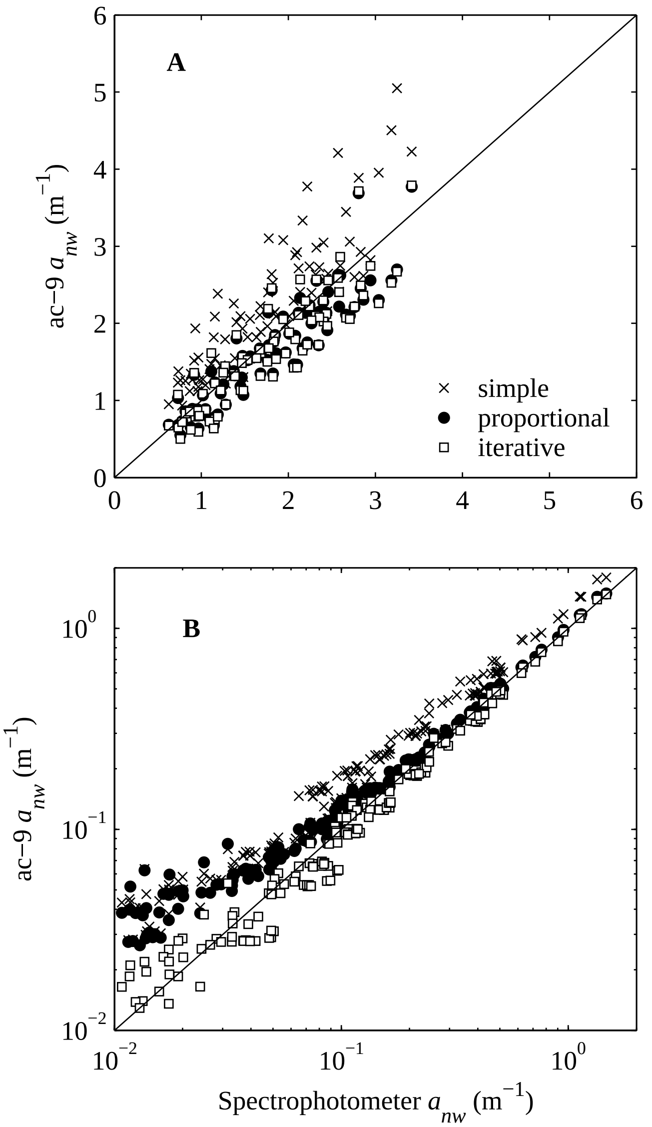


***Figure 1. Comparison of the non-water absorption coefficients (particles+CDOM) measured spectrophotometrically with ac-9 values corrected with three different approaches. The simple scattering correction overestimated absorption over the whole range. (A) Variability between the data was greatest at higher absorption (proportionally corrected $a_{nw}(412) > 1.5\ m^{-1}$). Data shown for 412, 440, and 488 nm. (B) For proportional $a_{nw}(412)$ between 0.5 and 1.5 $m^{-1}$ there was good agreement between both the proportional and iterative scattering corrected data and that from the spectrophotometer, but the proportional correction overestimated absorption when $a_{nw}(412)$ was below 0.5 $m^{-1}$. Data shown for $412 \leq \lambda \leq 675$ nm.***

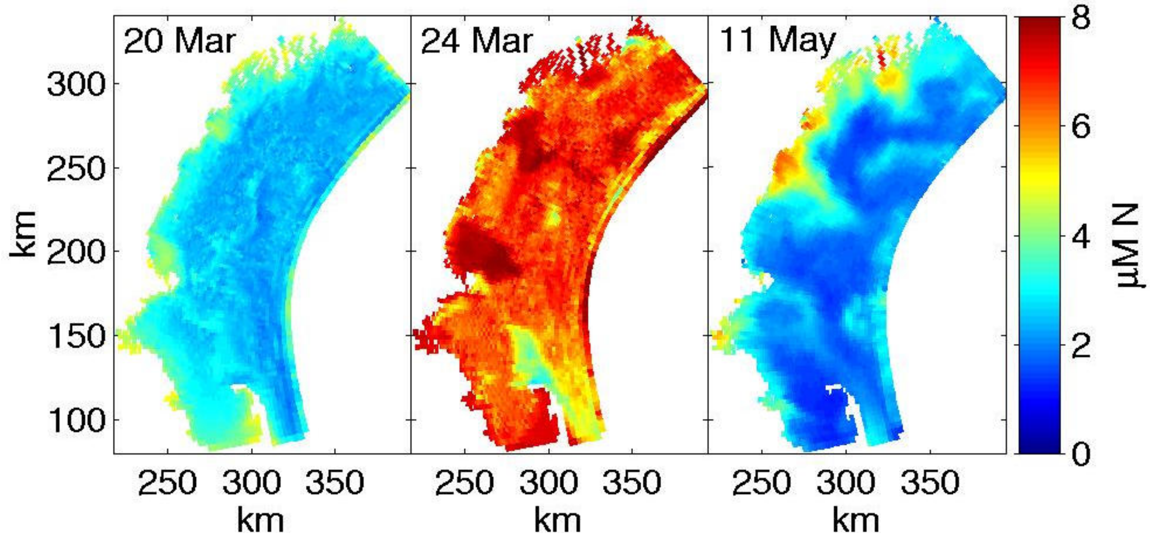


***Figure 2. Simulated phytoplankton biomass in 1993. Prior to the spring bloom (March 20), biomass is highest in shallow areas due to less light-limitation. During the spring bloom (March 24), highest concentrations are found in highly-stratified water associated with the Merrimack and Saco River outflows. Post-bloom (11 May), highest values are found along the coast due to coastal nutrient sources (including river water) and coastal upwelling events; the variable winds drive intermittent injections of biomass into the basin interior.***

**IMPACT/APPLICATIONS**

Coastal ecosystems are highly complex and multidimensional. Understanding how they function and determining the important spatially and temporally varying processes that regulate them requires interdisciplinary and multi-faceted approaches. The combination of detailed spatially resolved observations and 3-dimensional modeling (with data assimilation) has great potential to contribute to answering these questions. Optical properties contain a lot of information about biological and chemical aspects of a coastal system. They cannot be accurately interpreted, however, without considering time-varying physical processes, which are directly responsible for moving material around and indirectly important through their role in regulating biological and chemical processes. Integration of models of optical properties into our physically realistic ecosystem simulations will contribute to better understanding of the processes contributing to optical variability in coastal waters.

**RELATED PROJECTS**

This project builds on previous projects in the Sosik laboratory supported by ONR. This previous work led to collection of a large database of optical properties of the Gulf of Maine, via conventional shipboard sampling and towed vehicle surveys. See http://www.whoi.edu/science/B/sosiklab/ for more details.

This project also builds upon prior modeling work in the McGillicuddy laboratory supported by the ONR YIP ("Physical Forcing of Phytoplankton Abundance in the Gulf of Maine – Georges Bank Region").

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**HONOR/AWARDS/PRIZES**

Heidi Sosik, Woods Hole Oceanographic Institution Coastal Ocean Institute / Ocean Life Institute Fellow. 2003-2005.

Dennis McGillicuddy, American Society of Limnology and Oceanography Lindeman Award. 2000.